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LORD RUTHERFORD

1871—1937

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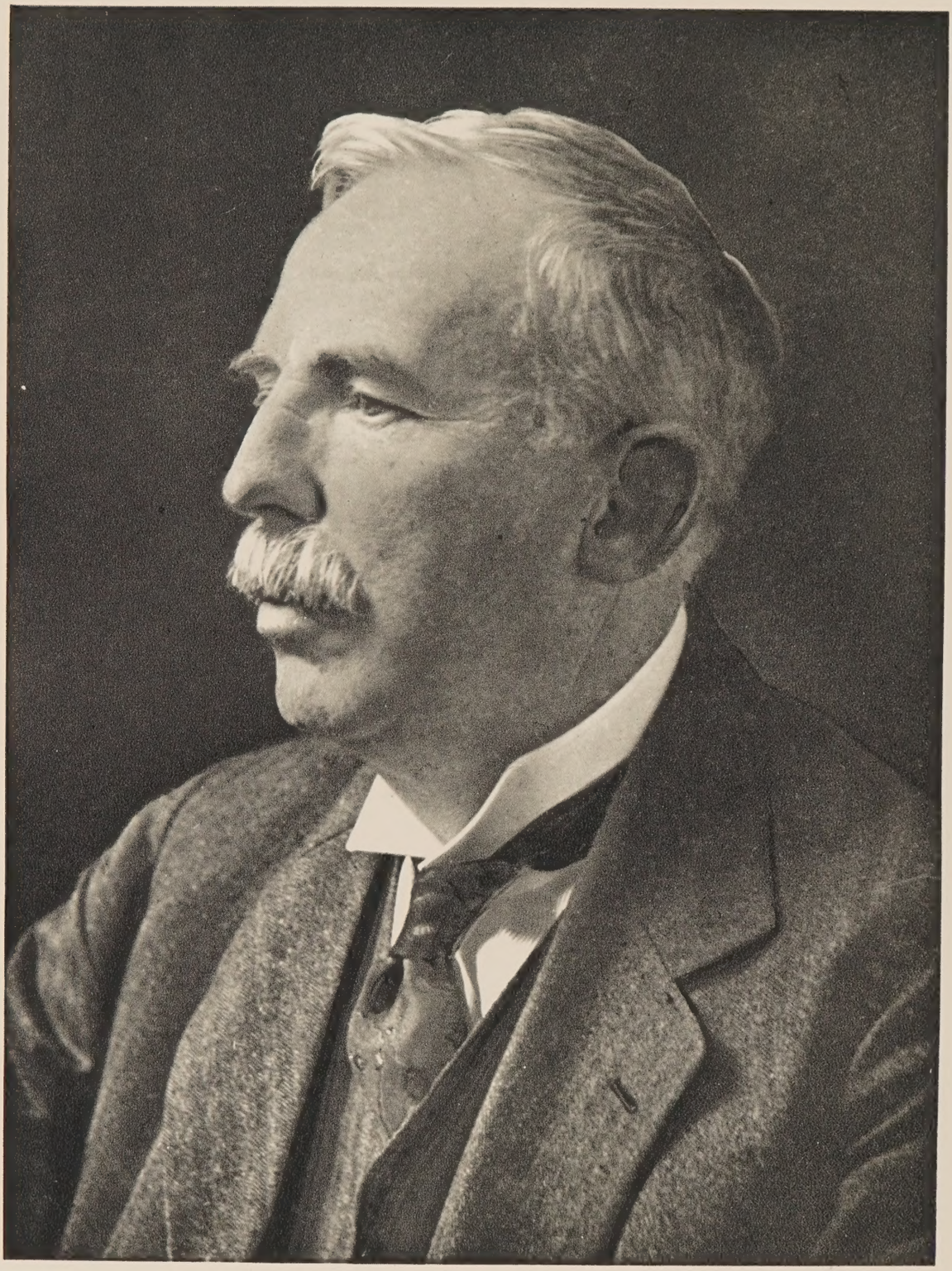

Rutherford

LORD RUTHERFORD

1871–1937

New Zealand, 1871–1894

If a new country is peopled with a good stock, its future is assured. Such has been the happy fortune of New Zealand, which to-day justly claims Rutherford as her greatest son. New Zealand was sighted by Tasman and visited by Captain Cook, F.R.S., who stayed long enough to bequeath the flea, the black rat and the pig to the Maoris. The country received its first white settlers in 1817, but the main colonization followed about 1840—less than a hundred years ago !

Among the early settlers was one of the Rutherfords, for the most part Scots and a virile border-folk. His son James, and Martha his wife, another New Zealand settler from Sussex, had four sons and eight daughters. Ernest, the second son and fourth child, was born on 30 August, 1871, near Nelson, at Brightwater, and there he went to the State primary school, whence he obtained a scholarship to the Nelson School. About this time his father had moved to Pungarehu, Taranika Province, where he had a flax farm and mill and a rope walk. Rutherford is reported on good authority to have been a normal, happy, unassuming boy, but with unusual powers of concentration—the secret of his success in life. He shot pheasants and wild pigeons, played forward at Rugby football, caught eels and brook trout, nearly drowned himself bathing, took clocks to pieces, made water wheels (like Newton), photographed, loved reading and music ; he also won prizes and scholarships for English, History, French, and Latin. He was greatly helped by a good schoolmaster, W. S. Littlejohn, who taught him sound mathematics, and, in a very small class, chemistry and physics. He obtained a scholarship to Christchurch College, Canterbury (part of the University of New Zealand), which at that time (1890) had seven professors and about one hundred and fifty students. Here two men in particular influenced him : Professor A. W. Bickerton, who taught physics and chemistry and was highly original, although " heterodox in all his views and erratic in his methods " ; and Professor G. H. H. Cook, whose mathematics was sound and orthodox.

Rutherford's thesis in physics was on " Magnetization of Iron by High-frequency Discharges ", and the necessary experiments were carried out in a cold and draughty den. He showed that high-frequency currents from a small Tesla coil, with a frequency of about 100 million cycles a

second, would strongly magnetize iron, contrary to the belief of the day. The explanation was given by the late Lord Rayleigh who pointed out that with damped oscillations the balance of the total current must necessarily be unidirectional.

Rutherford's second paper was on " Magnetic Viscosity ", published (1896) in the *Transactions of the New Zealand Institute.* By this time he was able to send wireless (Hertzian) waves down the 60 feet of the shed, and through walls, detecting them at the other end. He had also, with prophetic insight, read a paper to the Science Society (1891) entitled " The Evolution of the Elements".

For a time he endeavoured to impart some of his knowledge to some restless and rather unruly boys of the High School, Christchurch, N.Z. ; but—the great opportunity came—the spirit of the Prince Consort kindled New Zealand, and the Commissioners of the great 1851 Exhibition elected the brilliant and promising youth to a Scholarship, and he sailed for Cambridge University.

Most of the preceding account is culled from a description of the early years of Rutherford collected by Professor C. C. Farr, F.R.S., Canterbury College, N.Z.

Cambridge, 1895–1898

On his arrival in England Rutherford joined Trinity College, Cambridge, where later he was elected to a Coutts Trotter Studentship. A wise University regulation had just been made which enabled graduate students of other universities to join Cambridge as Research Students and obtain a B.A. degree after two years' residence. Sir J. J. Thomson has stated that Rutherford was the very first research student to join him in the Cavendish Laboratory, while J. S. Townsend was a close second.

Rutherford at first continued and developed his work on the magnetic detector already begun in New Zealand and his results were published in *Phil. Trans.*, A, vol. 198, p. 1 (1897), in a paper which may still be read with great interest. After testing many types of iron and steel of various lengths and diameters, he finally made a bundle of twenty steel wires (1 cm. long, each 0·007 cm. diameter) and wound them with eighty turns, two layers, of fine insulated wire having a total length of six inches ! The ends of this small solenoid were connected between two straight rods in line, which formed the aerial. The waves came from the oscillator through space and caused a current in the aerial. This current passing round the coil altered the magnetism of the steel and this change was indicated by the deflection of an adjacent small mirror

magnetometer. Rutherford used a vibrator or oscillator such as Hertz employed in his classical experiments on wireless waves, and the plates were about 16 inches square, but for long ranges he used zinc plates, 6 feet by 3 feet. The sparks between the central knobs were excited either by a Wimshurst machine or a Ruhmkorff coil, and these were equally effective. There was one drawback ; the detector had to be remagnetized after the receipt of a signal, a difficulty which Marconi later overcame by the revolution of an endless steel band passing a " wash-out " magnet. Detection of wireless waves, 6 or 7 metres long, by this method, was first made by Rutherford across Jesus Common, Cambridge, over a distance exceeding a quarter of a mile, and later from the top of the Cavendish Laboratory to Park Place, with many brick and stone buildings between oscillator and receiver half a mile apart. Sir Joseph Larmor states that there were also signals sent in this manner from the Cavendish to the Observatory about two miles away. No apology is needed for dwelling at some length on this important pioneer experiment. He received no benefits or specific recognition for his invention, and refused to act as " expert witness " with reference to the discovery.

Rutherford next joined in the investigations on the " Conduction of Electricity through Gases ", about which Sir J. J. Thomson published his famous book in 1903—a book which opened great vistas of new regions of physics and was for a number of years almost a bible for physicists. In the index are 25 references to the five or six years of Rutherford's work. Rutherford had ingenious methods for measuring the velocities of the ions produced by Röntgen rays. First he measured the ionization current between two parallel plates ; then he switched off the rays, instantly put on a high potential and thus swept out all the ions of one sign to a plate and measured the charge that this carried with an electrometer. Thus, without knowing either the number or the charge of the ions, it was easy to find the sum of the velocities of the ions in air or in any chosen gas. These added velocities were found to be 10 cm./sec. for hydrogen and 3·2 for air, as for a gradient of 1 volt per centimetre. By another method he measured the velocities of each kind of ion ; while his most ingenious scheme was to toss negative ions up and down by an alternating potential until they just reached an upper parallel plate joined to an electrometer. Rutherford was the first to measure the coefficient of the rate of recombination of ions. All of which justified his remark that " Ions are jolly little beggars, you can almost see them ! "

In the meantime great events were happening in France. Henri Becquerel had shown that uranium was radioactive (1896) ; Marie Curie

had discovered polonium ; Pierre and Marie Curie had found radium (1898); while Debierne next year produced actinium, and all these bodies had new, strange, complex properties. At Cambridge, Rutherford, now highly trained, began to study the radiations from uranium, and when he was appointed Macdonald Research Professor of Physics at McGill University, Montreal, in succession to H. L. Callendar, he carried this work with him with far-reaching results.

McGill University, 1898–1907

At Montreal, Rutherford continued his work on the radiations from uranium and found that there were two types, which he named alpha and beta rays, whose absorptions by aluminium foil were in the ratio of a hundred to one. He noted in the case of thorium a yet more penetrating type, but the name gamma rays was given later by Villard. About the same time R. B. Owens began work at McGill on the radiations from thorium compounds and found some perplexing new properties, for a draught of air would reduce his electroscope readings to a third of their value in still air, and " something " would pass through paper which could not get through quite thin layers of mica or metal foil. Rutherford examined this problem in a systematic way and found that there was an " emanation ", quite different from ionized air, for it would pass through cotton wool or red hot metal tubes, losing half its strength about every minute. Moreover, this substance would render other bodies radioactive, so that there were now four things to think about in the case of thorium—alpha rays, beta rays, emanation, and " induced " or " excited " activity, later known as " active deposit ". It was well remarked at the time that " it will be seen that radioactivity is a very complicated phenomenon ". This discovery of thorium emanation (thoron) was an important advance, followed by Dorn (1900) finding radium emanation with a half-value period of about four days. This, too, gave rise to " induced radio-activity " as Mme. Curie found.

Sir William Crookes ingeniously extracted by chemical methods uranium X—a highly radioactive material relatively small in quantity—from uranium nitrate, which thereby became weaker ; but the new substance grew weak (half-value period one month) and the original uranium recovered at the same kind of rate. Rutherford and Soddy somewhat similarly extracted thorium X from thorium and watched the former, at first strongly radioactive, weaken day by day, following an exponential law, while the original thorium recovered its radioactivity in a strictly complementary manner. In this case the period to half-value, regardless of age, was four days.

With this somewhat scanty but definite evidence,* Rutherford and Soddy (1902) boldly set forth the theory of radioactive change. They claimed that radioactivity was an *atomic* property, independent of physical surroundings or chemical composition, and it was stated that " the normal or constant radioactivity possessed by thorium is an equilibrium value, where the rate of increase of radioactivity due to the production of fresh active material is balanced by the rate of decay of radioactivity of that already formed " (*Phil. Mag.*, vol. 6, 3, p. 569, 1902).

The importance of the word " material " may be emphasized. A year later came a clearer statement ; writing of a single radioactive substance, the principle is laid down :—" The rate of the change of the system at any time is always proportional to the amount remaining unchanged ". Here speaks the perfect actuary dealing with the mortality tables of disintegrating atoms. He continues : " The proportional amount of radioactive matter that changes in unit time is a constant ". This constant for any given material is here called for the first time the " radioactive constant ". It is of course simply and closely connected with the half-value period, and its reciprocal is the average life of the atoms.

After these general principles had thus been laid down there was little stumbling in their application. Rutherford, with consummate skill, mastered the radium family, viz., radium, radon, radium A–F, all in strictly linear descent. He identified radium F with Mme. Curie's polonium, for the two had the same period of decay to half-value. He also postulated the existence of two " rayless " changes RaB and RaD, which are now known to project beta particles, but at the time they were mere go-betweens, devoid of all physical properties, but none the less " real ". He presented the whole fabric complete with theory to the Royal Society in his Bakerian Lecture. (*Phil. Trans.*, A, vol. 204, pp. 169–219, 1904.)

In 1908 Boltwood was praising the then recent papers of Rutherford and Geiger. " These are quite up to the top notch of your own standard and I think the best since the Bakerian Lecture period, which in my opinion can never be beaten. That Bakerian Lecture is going down through history as *the classic*, and every time that I turn to it I am comforted with the thought that I possess a copy ".

Rutherford was elected Fellow (1903) and awarded the Rumford Medal (1905). Before this, however, he had revisited his home in New Zealand and married (1900) Mary G. Newton, only daughter of Arthur and Mary de Renzy Newton, Christchurch, N.Z.

* Rutherford had also found an exponential law of decay for thorium emanation and active deposit.

At McGill he proved his capacity to inspire a group of research workers, of whom a few only can be named. There was Hahn, discoverer of radiothorium and radioactinium, who was working out the thorium family ; Godlewski, who was exploring the analogous changes of the actinium family ; H. L. Cooke, who hunted for penetrating radiation and found that " in fact this radiation seems to be everywhere with practically uniform intensity " (*Phil. Mag.*, vol. 6, 6, p. 403, 1903) ; S. J Allen, examining snow and rain for radioactive matter, and following Elster and Geitel in collecting active deposit from the atmosphere on negatively-charged wires, and finding the decay period, 45 minutes, suggestive of radium A, B and C as the main substances collected ; Miss Brooks, who noted that the excited activity of radium would to some extent find its way from an isolated central plate to the walls of the surrounding chamber, about which Rutherford wrote (1904)—" Since radium A breaks up with an expulsion of an alpha particle, some of the residual atoms constituting radium B may acquire sufficient velocity to escape into the gas, and are thus transferred by diffusion to the walls of the vessel ". This was a statement of the recoil principle later used by Hahn and others to discover new radioactive elements.

The great benefactor of McGill, Sir William Macdonald, presented to the laboratory a liquid-air machine and a hundred milligrammes of Ra Br_2, and with these Rutherford quickly showed that radium emanation was a gas which would condense in a spiral tube immersed in liquid air at a temperature of about — 153° C. At ordinary temperatures the emanation behaved like a gas and diffused at a rate suggestive of high molecular weight. Moreover, it disintegrated at a rate independent of the volume it occupied, so that atoms were not disintegrated by the radiation from adjacent atoms.

Curie and Laborde had found that a gramme of radium would produce heat continuously at the constant rate of about 100 calories an hour. Rutherford and Barnes confirmed this and found how the heat arose with reference to the different types of radiation, also with respect to the various members of the radium family. Rutherford made a calculation relating to this high output of energy and added " there is no reason to suppose that this enormous store of energy is possessed by radioelements alone " (*Phil. Mag.*, vol. 6, 5, p. 587, 1903). Indeed, were it possible to collect a pound of radium emanation the rate of output of its radiant energy would at first be equivalent to 10,000 or 100,000 horse-power. Rutherford and Soddy had stated that " on the disintegration hypothesis this energy is derived from the latent energy in the radium atoms and is released in the successive stages of their disintegration ". This view did

not at first commend itself to Lord Kelvin who wrote : " I venture to suggest that etherial waves may supply energy to the radium ". Even more rashly he continued : " A simple *prima facie* view is to regard the gamma rays as merely vapour of radium " and, while admitting beta rays to be electrons, added : " alpha rays are atoms or molecules of matter, probably atoms of radium, or perhaps molecules of bromide of radium, either deprived of electrons or having less than their neutralizing quantum ". These quotations are made to illustrate the great difficulty there was in the early stages of deciphering the hieroglyphics of radio-activity and how skilful Rutherford was at so hard a task. The change he introduced into atomic theories was not a reformation but a revolution ! It is right to add that at a subsequent meeting of the British Association Kelvin publicly withdrew his etherial waves and accepted Rutherford's disintegration views.

A further important result followed from a knowledge of the heating effects of radium, because R. J. Strutt, now Lord Rayleigh, had measured the amount of radium present in igneous and sedimentary rocks, and a simple calculation proves that the heat from the radium was amply sufficient to check the cooling of the earth. J. Joly, in his review of one of Rutherford's books, wrote : " Professor Rutherford shows how completely the view, that the earth's age is no longer determinable from temperature gradient, is justifiable ".

Thus ended a controversy between schools with widely divergent views, which may be illustrated by two brief quotations :—

" In all probability a far longer period than 300 million years has elapsed since the latter part of the secondary period ". Thus wrote Darwin in his *Origin of Species* (1859, p. 287) ; while Kelvin was equally emphatic :—

" Consolidation of the earth took place more than 20 million and less than 40 million years ago ".

The distribution of radioactive products, such as helium and RaG (lead), in radioactive ores affords to-day the best estimate of the ages of successive strata, and the age of the earth as a whole.

In 1903 Rutherford published important results on the nature and measured properties of alpha rays from radium, which he passed between parallel plates and deflected with magnetic and electrostatic fields. He found the ratio of charge to mass of an alpha particle to be about 6000, which suggested a helium atom of mass 4 and with charge $+ 2e$, as was finally proved. He found the velocity of the alpha particle to be about $2{\cdot}5 \times 10^9$ cm./sec.—rather too large a value. But these early results gave a clear enough picture of the nature of this radiation. In 1905,

while still at McGill, Rutherford had fired alpha particles into a testing chamber and determined the total charge carried per second. Knowing the double charge that each carried, he was able to state that the number of alpha particles issuing from a gramme of radium every second was about 6×10^{10}, and of beta particles $7 \cdot 3 \times 10^{10}$, while the half-value period of radium was estimated at 1850 years. (*Phil. Mag.*, vol. 6, 10, p. 193, 1905) These figures were based on an erroneous radium standard and on too low a value of the electronic charge, yet for first measurements they were astonishingly, perhaps luckily, good. Thus Dewar (*Proc. Roy. Soc.*, A, p. 81, 1908) writes that he had actually measured the amount of helium produced in one day as from a gramme of radium, while Rutherford had calculated (1906) the amount from the number of alpha particles projected, with the further assumption that each was an atom of helium with a double electronic charge ; Dewar adds : " the agreement between experiment and the theoretical prophecy of Rutherford is almost too wonderful, substantiating as it does the accuracy of the theory of radioactive changes that he has done so much to initiate and develop ". Dewar found 0·30 cub. mm. of helium per day and Rutherford 0·37, as from a gramme of radium. The more correct value to-day seems to be 0·43.

Rutherford was interested in the range of the alpha particle and found that the measured length was the same whether determined by photography, fluorescence, or ionization. He was surprised to find that the alpha particle ceased to produce any effects when the velocity fell below about 60 per cent. of its initial velocity, and while it still retained much energy.

Those who approach a battlefield first meet with the fire of long-range guns and then enter the successive zones of various projectiles. Sir William Bragg, P.R.S., then Professor of Mathematics and Physics at Adelaide, sent a letter to Rutherford the contents of which gave him great pleasure. Bragg and Kleeman had approached the " battlefield " of radium with a shallow testing chamber and found that there were six distinct zones of fire ; gamma rays, beta particles, and finally alpha particles in the following order, and with the stated ranges in centimetres of air :— RaC 7·06, RaA 4·83, RaEm 4·23, Ra 3·50. This discovery opened up large fields of investigation and it was necessary to measure the energy of each type of alpha particle, and to determine the stopping power of the atoms of the various elements.

This account of Rutherford's activities at McGill University is necessarily incomplete. Those who wish to study the evolution of radioactivity and, at the same time, of the mind and powers of Rutherford

during this period may compare four books—*Radioactivity* (1904) ; also the second edition, much enlarged (1905) ; *Radioactive Transformation* (1906), founded on his Silliman Lectures—these were all published while Rutherford was in Montreal, and they may be compared with *Radioactive Substances* (1913) which includes the fine work done by him and his co-workers during his first years at Manchester.

Sir J. J. Thomson wrote in *Nature* (vol. 140, 3548, p. 752, 1937) :—

" Rutherford's scientific activity was never greater than when he was at Montreal. In the years between his first coming to Cambridge and leaving Montreal . . . he had published between forty and fifty papers ; a few of these were joint papers, but the great majority were about researches of his own which had led to results of first-rate importance and which could not have been obtained by anyone who was not an experimentalist of the very first order. In those days, laboratories had no funds to buy instruments as sensitive as those now available, and the detection of small effects required exceptional skill, patience, and self-criticism ".

Manchester, 1907–1919

In 1907 Rutherford accepted the Langworthy Chair of Physics in the University of Manchester. His predecessor in the Chair, Professor Arthur Schuster, was largely responsible for the invitation which was sent from Manchester to Rutherford. The laboratories to which he came were fairly new (they had been opened in 1900), and Schuster had devoted much care to their design and equipment. Two sub-departments, electrotechnics (later separated into an independent department under Professor R. Beattie) and electro-chemistry, were housed in the Physics building and under the control of the Langworthy Professor. The laboratories as a whole were well equipped for electrical work, and there was an efficient liquid-air machine. In other words, the laboratories were so equipped that Rutherford could continue, with a minimum of delay, the work he had begun in Canada. He was not hampered by excessive teaching or administrative duties, he had a capable teaching staff to assist him, and he found in Mr. William Kay a young, energetic, and exceptionally capable laboratory steward. The department ran smoothly and Rutherford was able to throw a large part of his amazing energy into the development of a school of radioactive research. In a short time he attracted so many research workers from all parts of the world that the laboratory became seriously overcrowded. Conditions were much relieved by the building, some four or five years later, of additional research rooms and the removal of the sub-department of electro-technics to a separate block.

Two circumstances facilitated the beginning of work in Manchester. He found there Schuster's young assistant, H. Geiger, who became an admirable second in furthering the development of a research school ; and in 1908 the Akademie der Wissenschaften of Vienna lent him 250 mgm. of radium, a very considerable amount of radium in those days. The radium preparation was of low concentration and so bulky that it was unsuitable for most experiments. Rutherford therefore developed a new way of using radium—the use of radium in solution as a source for its emanation, which could be pumped off when required. The apparatus for this purpose and the method of purifying the emanation were worked out with the aid of Royds (*Phil. Mag.*, November, 1908). This was a significant advance in technique, for it made possible a regular supply of radium emanation and active deposit for the many experiments in progress in the laboratory.

Rutherford's work at McGill had firmly established the transformation theory propounded by himself and Soddy, and the general scheme of the radioactive families was sufficiently clear, at least in outline, by 1907. At the time of his arrival in Manchester he was more keenly interested in the radiations from the radioactive substances, and especially in the α-rays, than in the substances themselves.

One of his earliest major contributions in Manchester was the beautiful work with Geiger (*Proc. Roy. Soc.*, A, vol. 81, p. 141, 1908), in which the number of α-particles emitted per second per gramme of radium was accurately and directly measured for the first time. It is difficult now to realize the many difficulties which had to be overcome before they were able to detect a single α-particle by means of its electrical effect. It was a technical feat of a high order, all the more impressive for having been accomplished with the simplest apparatus and in a very short time. The result of this measurement was of the utmost value in general atomic theory, as well as in radioactivity. When combined with the measurement of the total charge carried by a stream of α-particles (Rutherford and Geiger, *Proc. Roy. Soc.*, A, vol. 81, p. 162, 1908) this result showed clearly that the normal α-particle was doubly-charged, and gave a value for the unit of charge which was at least as reliable as any available at the time.

Rutherford's earlier work had convinced him (and most other physicists) that the α-particles were doubly-charged helium atoms. Although the new work with Geiger strongly supported this view, he evidently felt the need of a direct identification. This followed in the experiment with Royds (*Phil. Mag.*, vol. 17, p. 281, 1909). They succeeded in preparing glass tubes with walls so thin that α-particles

could pass through and yet so strong as to withstand atmospheric pressure. Such an " α-ray tube " was filled with radon and the emitted α-particles were allowed to emerge into a previously evacuated space. After a few days, an electrical discharge was passed through this space and the characteristic spectrum of helium appeared. This experiment created great interest on account of its simple directness and beauty.

A quantitative continuation of this work—the measurement of the rate of production of helium by radium—was carried out with his friend, B. B. Boltwood, who spent a year's leave in Manchester (*Phil. Mag.*, vol. 22, p. 586, 1911). This formed a fitting conclusion to this particular chapter of Rutherford's work on the α-particles, for, by combining these results with those of the counting experiments, it was possible to deduce Avogadro's number in the most direct manner conceivable. It is worth stressing that in principle Rutherford counted the number of molecules in a cubic centimetre of gas just as directly as one can count the number of marbles in a box. It is not a little remarkable that Rutherford, who, with Soddy, destroyed one of the most cherished beliefs of the atomists —that of the indestructibility of the atom—should also have been the one to provide some of the most convincing evidence of the existence of atoms and to verify so brilliantly some of the predictions of the kinetic theory of gases.

It was, however, the experiments on the scattering of α-particles which led to Rutherford's greatest and most fruitful contribution to atomic theory. In the experiments on the counting of the particles it had been noticed that traces of residual gas in the long tube down which the α-particles passed had an influence on the counts. This effect was ascribed to a small scattering of the α-particles, which was investigated later by Geiger (*Proc. Roy. Soc.*, A, vol. 81, p. 174, 1908 ; vol. 83, p. 492, 1910). Then came the surprising observation by Geiger and Marsden (*Proc. Roy. Soc.*, A, vol. 82, p. 495, 1909) that an α-particle sometimes experienced an exceptionally violent deflection, seldom, it is true, but far too often to be explained on the basis of the previous measurements of the scattering. Rutherford must have pondered deeply on this curious effect. Professor Geiger writes : " One day (in 1911) Rutherford, obviously in the best of spirits, came into my room and told me that he knew now what the atom looked like and how to explain the large deflections of the α-particle. On the very same day I began an experiment to test the relation expected by Rutherford between the number of scattered particles and the angle of scattering ". The genius of Rutherford had seized upon an apparently unimportant detail and transformed it into a clue to the problem of the inner structure of the atom. The

nuclear theory of atomic structure was published in a surprisingly complete form in 1911 (*Phil. Mag.*, vol. 21, p. 669, 1911). Supported at first by the preliminary experiments of Geiger on the variation of scattering with angle, it was in the next few months confirmed in its minutest details by a beautiful series of accurate quantitative tests. It would be difficult to exaggerate the influence of the nuclear theory of atomic structure on the whole range of the exact natural sciences, and the theory will surely rank as the greatest of all Rutherford's contributions to physics.

Soon after the publication of the nuclear theory came two researches which are now classical. The first of these was Bohr's earliest contribution to atomic physics, in which he applied quantum-mechanical principles to the Rutherford model of the atom. Bohr had spent a few months in Manchester in the early summer of 1912, where he began to think about the role played by the quantum of action for the stability of the Rutherford atom. Only after his return to Denmark, however, did he produce his great paper on the constitution of the atom, in which he showed how the fundamental rules of the spectra of the elements could be explained in a very simple way. The second piece of work was Moseley's brilliant investigation of the X-ray spectra of the elements, in which he demonstrated the function of the nuclear charge in determining X-ray spectra and established the importance of the concept of atomic number. These two researches, which are among the most illustrious of a long line depending upon Rutherford's nuclear atom, undoubtedly owed much to his personal inspiration.

Not long afterwards, the Manchester research school was almost completely dispersed as a result of the outbreak of war. Much of Rutherford's time was taken up by war work, as well as by the difficulties of running his department with a heavily depleted staff. In 1919, however, he was able to publish the results of yet another epoch-making research, again made with α-particles. In four papers published in the *Philosophical Magazine*, vol. 37, he proved conclusively that the long range particles earlier shown by Marsden to be produced when α-particles were fired into hydrogen were in fact fast hydrogen nuclei, and he showed that identical particles were produced by the collisions of α-particles with *nitrogen*. The explanation—that these protons were the result of the disruption, or " artificial disintegration ", of the normally stable nitrogen nucleus—was so revolutionary, and so pregnant with far-reaching implications, that it clearly needed to be supported by very complete experimental evidence. Rutherford obtained the necessary support by an admirably designed series of control experiments. He did

the whole of the experimental work, with Kay's assistance in taking observations of scintillations. The further development of this work, and its extension to other nuclei, belongs to the Cambridge period.

Of the large amount of work on the β-radiation of the radioactive elements which was carried out in the Manchester laboratory, the first major research done by Rutherford personally was that, with Robinson, in 1912–1913 on the natural β-ray spectra of radium B and radium C. The important work of von Baeyer, Hahn, and Meitner had already shown the presence of definite groups of electrons with characteristic speeds in the emission of most β-ray bodies. Rutherford wished to have as complete and detailed information as possible on these β-ray groups in order to see what connexion there might be between them. In the analysis of the results of this work, even in its early stages, he was clearly being guided by a concept closely analogous to that of the " energy levels " of later atomic theory, although at this stage it was still assumed that the β-ray lines were formed by the disintegration electrons coming from the nucleus. These experiments were followed by an investigation (with Robinson and Rawlinson) of the secondary β-ray emission excited in heavy metals by the γ-radiation of radium (B + C). They found that the characteristic groups again appeared, showing that the electrons of these groups were due to a secondary effect and were distinct from the disintegration electrons. They also noticed that the velocities of these groups changed slightly from metal to metal and they suggested that this effect would lead to a clear understanding of their origin. These experiments gave a new orientation to our ideas on the origin of β-ray spectra, but their development had to wait for some years, for at this stage the war intervened and the work had to be broken off.

Much important work on the γ-radiation was carried on under Rutherford's general direction, by Gray, Florance, Chadwick, Russell, and others. Many of the implications of these γ-ray researches were not fully appreciated until a much later stage in the development of knowledge of the properties of radiation. For example, the experiments of Gray and of Florance showed that the quality of the γ-radiation scattered from lead varied markedly with the angle of scattering. In this respect the γ-rays appeared to show a different behaviour from the X-rays, of which the scattered radiations were similar in quality to the primary beam. It was difficult at that time to draw any definite conclusions since there was no information, except from absorption measurements, about the homogeneity of the primary γ-rays. These results were, however, the first dim indications of the Compton process of scattering. Another very interesting experiment was the measurement by Rutherford and Andrade

(*Phil. Mag.*, vol. 27, p. 854 ; vol. 28, p. 262, 1914) of the wave-lengths of the γ-rays from radium (B + C). In this work the " transmission " method of obtaining reflexions from crystal planes was used for the first time—an ingenious arrangement of the slit and crystal which avoided the necessity of adjusting the crystal for the very small glancing angles required. Rutherford also (with Richardson and others) made a full analysis, by the absorption method, of the complex γ-radiations from a number of radioactive elements.

Other work, less easy to classify, in which Rutherford was engaged during his stay in Manchester included : (with Geiger) observations on the fluctuations in the α-particle emission, for which Bateman developed the mathematical treatment ; (with Robinson) a detailed examination of the heating effects of radon and the constituents of the active deposit ; arising out of this work, owing to certain discrepancies between the observed and calculated heating effects, he made (with Robinson) accurate measurements of the specific charge and the velocities of the α-particles from a number of bodies ; (with Chadwick) on a precision method of comparing γ-ray activities ; (with Nuttall) on the scattering of α-particles by light atoms ; and (with Wood) on long range α-particles.

A great deal of other important work in radioactivity was carried out in the laboratory during the same period. It is impossible to discuss all of this, even in outline, but mention should be made of Geiger and Nuttall's measurements of the ranges of α-particles and their establishment of a relation between the range of the α-particle and the decay constant of the radioactive element, a very important relation which has recently received an explanation on the basis of the new quantum mechanics. These range measurements led to the discovery of the short-lived elements actinium A and thorium A and the work of Geiger and of Moseley and Fajans on the periods of these elements. There should be further mentioned the work of Darwin, Marsden, and Makower on the branching in radioactive series ; of Makower and others on problems connected with the recoil atoms ; and the contributions of von Hevesy and of Russell to the chemistry of the radioactive substances. Finally—outside of the work in radioactivity—it should be recalled that in 1915 Evans, who had carried out much optical work in the laboratory, proved definitely that the Pickering series, a series of lines first observed in some stars, was to be ascribed to helium, and not to hydrogen, as had been assumed before Bohr put forward his theory of the constitution of atoms and the origin of spectra. Bohr had, indeed, suggested such an experiment as a test of his theory, when (in March, 1913) sending the first draft of his paper for Rutherford's comments.

Considerable advances in theoretical physics were also made from the department. The opportunity for theoretical work was due to Schuster, through whose wise generosity a Readership in Mathematical Physics was instituted. This Readership was held in turn by Bateman, Darwin, and Bohr. Darwin and Bohr both made valuable contributions to the problems connected with the passage of charged particles through matter. Darwin, passing to an entirely different field, did some very fine work on the theory of X-ray reflexion by crystals. He also collaborated in experimental work with Marsden in radioactive experiments and with Moseley in X-ray spectroscopy.

A development, begun in Manchester and continued later in Cambridge in a more general form, was the institution of a training class for young men at the beginning of their research course. As in the course of years ever more young physicists came to work under Rutherford, it became clear that much time and trouble would be saved by training them, on their entry into the laboratory, in the technique of radioactive methods. A practical course was developed by Geiger, in which these beginners carried out a series of experiments on the analysis of decay curves, measurements, etc. Only after passing through this course was a beginner received into the research school and allowed to proceed with his particular field of work. The experiments carried out in this class were incorporated into the well-known book of Makower and Geiger, *Practical Measurements in Radioactivity.*

The writers are indebted to H. Geiger, H. Robinson, and A. B. Wood for their information about this period.

Much of the later scientific work at Manchester, and earlier results at Cambridge, are summarized in *Radiations from Radioactive Substances* by Rutherford, Chadwick, and Ellis (Cambridge, 1930).

War Work, 1914–1918

The War produced marked changes in Rutherford's laboratory in Manchester. The " family " of research workers dispersed—joining various branches of the fighting forces.

In July, 1915, the Admiralty Board of Invention and Research (B.I.R.) was organized under the presidency of Lord Fisher. Rutherford was on the Panel of the Board and on the Sub-Committee dealing with submarine detection and location, besides other important matters. At that time, enemy submarines were just becoming troublesome ; later they became a menace.

It might have been supposed that a man like Rutherford could not " switch over " from atoms to submarines. No doubt such a change

required a great effort on his part, but he was equal to it and tackled the problem with his customary energy. The large research laboratory on the ground level was transformed into an acoustics laboratory with a large tank for studying under-water acoustics, about which little was known. His early work in this laboratory with Broca tubes, diaphragms, microphones, and various under-water senders and receivers demanded tests under service conditions. A research station was started at Hawkeraig, Aberdour, in November, 1915. Rutherford supplied a constant stream of apparatus and ideas to be tried out on ships and submarines at Aberdour. At the same time he continued his university work, and made frequent visits to London. He enjoyed his Aberdour visits ; the sea air and work on ships acted like a tonic. When he took a few days' rest after six months he was followed by a deluge of letters from the B.I.R. Professor Bragg took charge of the station, and Rutherford was a frequent and very welcome visitor. He was always brimming over with suggestions, and sometimes impatient with delays in obtaining ships for his experiments. In 1917 the B.I.R. station was moved to Parkeston Quay, Harwich, the headquarters of Admiral Tyrwhitt's famous fleet of destroyers and submarines. The work on hydrophones was continued and the Langevin piezo-electric method was developed and improved.

Rutherford also joined a mission of English and French engineers, chemists, and physicists to the United States, and they placed all the anti-submarine plans in progress in Great Britain before the leading scientific men and they in turn entered with whole-hearted enthusiasm in their further development, using the vast resources at their disposal. Rutherford stated that when the war was over a re-survey was made of all scientific methods which could be used to counter submarine warfare, and it was found that, during the war, none of these had been overlooked. Such devices would certainly have been of little use but for the intrepid courage and skill of British seamen.

Cambridge and the Cavendish, 1919–1937

When Sir J. J. Thomson, finding the double duty of directing a great laboratory and a great college too much for one man's strength, resigned the Cavendish Chair of Experimental Physics at Cambridge, Rutherford was the obvious choice for his successor. He left Manchester with many regrets, for it was the scene of great achievements and the home of many friends, but he looked forward to his work at Cambridge with keen anticipation. Bohr wrote in *Nature* (18 December, 1932) : " I remember on a visit to Manchester during the Armistice hearing Rutherford speak with great pleasure and emotion about the prospect

of his going to Cambridge, but expressing at the same time a fear that the many duties connected with this central position in the world of British physics would not leave him those opportunities for scientific research which he had understood so well how to utilize in Manchester". Bohr went on to say : "As everybody knows, the sequel has shown that this fear was unfounded. The powers of Rutherford have never manifested themselves more strikingly than in his leadership of the Cavendish Laboratory, the glorious traditions of which he has upheld in every way".

When Rutherford went to Cambridge in the summer of 1919 he took with him a great deal of apparatus from Manchester, including the Vienna radium, so that he was ready to start work immediately. He continued his investigation of the effects accompanying the passage of α-particles through nitrogen and oxygen, recorded in the series of papers in the *Philosophical Magazine* of 1919. The results of these experiments were given in his second Bakerian Lecture of 1920, "The Nuclear Constitution of Atoms". He gave further and conclusive proof that the long range particles from nitrogen were swift protons, by measuring their deflection in a magnetic field. This was the first great step in the deliberate transmutation of matter. He also discussed the nature of the "short range atoms" observed in nitrogen and oxygen, and concluded that they were a new kind of particle of mass 3 and charge 2, that is, an isotope of helium, liberated in the disintegration of nitrogen and oxygen. This conclusion proved to be wrong, for these "short range atoms" were found later to be "long range α-particles" emitted by the source of radium C. This is one of the very few instances in which Rutherford made a wrong deduction from his experiments. The apparent occurrence of this new particle—part of the structure of the nitrogen and oxygen nuclei—led him to consider generally the constitution of atomic nuclei. Using as the ultimate constituents the hydrogen nucleus and the electron, he suggested that simple combinations of these might exist which had not yet been discovered. It may be of interest to quote his own prophetic words forecasting deuterium and neutron : ". . . it seems very likely that one electron can also bind two H nuclei and possibly also one H nucleus. In the one case, this entails the possible existence of an atom of mass nearly 2 carrying one charge, which is to be regarded as an isotope of hydrogen. In the other case, it involves the idea of the possible existence of an atom of mass 1 which has zero nuclear charge. Such an atomic structure seems by no means impossible. On present views, the neutral hydrogen atom is regarded as a nucleus of unit charge with an electron attached at a distance, and the spectrum of hydrogen is ascribed to the movements of this distant electron. Under

some conditions, however, it may be possible for an electron to combine much more closely with the H nucleus, forming a kind of neutral doublet. Such an atom would have very novel properties. Its external field would be practically zero, except very close to the nucleus, and in consequence it should be able to move freely through matter. Its presence would probably be difficult to detect by the spectroscope, and it may be impossible to contain it in a sealed vessel. On the other hand, it should enter readily the structure of atoms, and may either unite with the nucleus or be disintegrated by its intense field, resulting possibly in the escape of a charged H atom or an electron or both". And further: "The existence of such atoms seems almost necessary to explain the building up of the nuclei of heavy elements; for unless we suppose the production of charged particles of very high velocities it is difficult to see how any positively charged particle can reach the nucleus of a heavy atom against its intense repulsive field".

The idea that there might exist small particles with no electric charge had, of course, been suggested many times before, but none of these suggestions so closely forecast the properties of the neutron we now know. Rutherford thought that these neutral particles might be formed in the electric discharge through hydrogen. Several experiments were made to test this idea, but they gave, of course, negative results. Rutherford never abandoned the idea that the neutron might exist, and in later years both he and Chadwick made unsuccessful attempts to detect this particle (*cf.* Rutherford and Chadwick, *Proc. Camb. Phil. Soc.*, vol. 25, p. 190, 1929).

After going over the ground of his previous work in this way, Rutherford, with Chadwick, extended the work on disintegration by the impact of α-particles on other elements. Improvements in the technique of scintillation-counting made observations much easier and more reliable, and it was rapidly shown that many of the lighter elements could be disintegrated, with the emission of long range particles (Rutherford and Chadwick, *Phil. Mag.*, vol. 42, p. 809, 1921). In a later paper it was shown with reasonable certainty that the long range particles were in all cases swiftly moving protons. In subsequent papers the observations were further extended and it was shown that nearly all the light elements, up to argon, were disintegrated in this way. The mechanism of the disintegration process was not at first clear. It was gradually realized that a kind of synthesis of the atomic nucleus probably took place, in which the α-particle was captured and incorporated into the nuclear structure, and a proton emitted. This capture of the α-particle was later shown very clearly and decisively in the beautiful experiments of

Blackett in which he observed and photographed disintegrations of nitrogen in the expansion chamber. The general view (*cf.* Rutherford and Chadwick, *Proc. Phys. Soc.*, vol. 36, p. 417, 1924) was that, while the ordinary Coulomb force must hold outside the nucleus, there must be attractive forces inside in order to hold the particles together. There must then be a critical surface around the nucleus at which the force is zero or the potential a maximum. In order to promote a disintegration, the α-particle had to penetrate within this critical surface. There should thus be a minimum velocity which the α-particle must have to produce a disintegration and the proton must escape from the nucleus also with a certain minimum velocity. The experiments gave general support to this view of the disintegration process. Estimates of the critical potential (which we should now call the height of the potential barrier) agreed reasonably well and the probability of disintegration also fitted in with this view. It is not without point to remark how well this general picture corresponds to our present ideas.

Pursuing this conception, Rutherford attempted to obtain further information about the potential barriers round atomic nuclei by investigating the scattering of the α-particles (Rutherford and Chadwick, *Phil. Mag.*, vol. 50, p. 799, 1925). He found that the scattering by light elements departed in a striking way from the normal scattering calculated on Coulomb forces. While the deviations occurred in about the expected region it was not possible to give a satisfactory explanation of the results. A still more striking result was obtained from the examination of the scattering by uranium. As uranium emits α-particles of 2·7 cm. range it was expected that α-particles of radium C′, of much greater energy, would be able to penetrate with ease into the uranium nucleus ; such penetration would be revealed by strong divergences from normal scattering. No such divergences were observed ; the forces experienced by the α-particle were the ordinary Coulomb forces. The radioactive data gave a radius of at least 7×10^{-12} cm. for the uranium nucleus, the scattering experiments said it was less than 3×10^{-12} cm. To escape from this dilemma, the suggestion was made that the outer parts of a nucleus were composed of neutral satellites. Rutherford himself developed this point of view later in great detail (*Phil. Mag.*, vol. 4, p. 580, 1927) in an interesting way, but without real success. The difficulty was too deep-seated. Classical mechanics failed to describe these events. The explanation was given by Gurney and Condon, and by Gamow, a year or so later, when they pointed out that the wave mechanics allowed the α-particle to escape from a nucleus through the potential barrier, and did not force it, as did the classical mechanics, to

climb over the top. This application of quantum mechanics to nuclear problems also helped to explain some of the phenomena of the artificial disintegrations and pointed the way to further advances.

The experiments of Coolidge in 1926 and 1927 on the acceleration of electrons by voltages as high as 600,000 volts suggested that there were no really serious difficulties in using voltages of this order to produce high-speed positive ions as well as electrons. At the Anniversary meeting of the Royal Society in 1927, Rutherford in his Presidential Address declared that it had " long been his ambition to have available for study a copious supply of atoms and electrons which shall have an individual energy far transcending that of α-particles and β-particles from radioactive bodies ". The first experiments of this kind in the Cavendish Laboratory were made by Allibone, who had been given leave from the Research Department of Metropolitan-Vickers, Ltd., in order to work on the production of high-speed electrons. Allibone's work on the design of high voltage tubes formed the basis on which much of the later Cavendish work grew. A great stimulus to these developments was given by the work of Gamow, and Gurney and Condon, on the passage of particles through nuclear potential barriers, further helped by Gamow's stay in the laboratory. For the first time it was possible to see how charged particles even of low energy could penetrate into the nucleus, and to calculate the probability of penetration. In this way Cockcroft came to the conclusion that protons accelerated by 300,000 volts should have a reasonable chance of disintegrating the lighter elements, and he was strongly supported by Rutherford in proceeding with the development of apparatus for experiment on these lines. About this time Walton arrived with many ingenious schemes for accelerating particles by indirect methods, similar to the method so brilliantly developed by Lawrence in the cyclotron. These methods proved unsuccessful and Walton joined forces with Cockcroft in the direct attack. A transformer was specially designed for the work by industrial friends ; rectifiers were built in the laboratory to provide a steady potential. A canal-ray tube formed a simple source of protons, and during 1930 attempts were made to disintegrate lithium by bombardment with protons. Unfortunately, in these early experiments the emission of γ-radiation was mainly looked for, and the results were negative. At this juncture a reorganization of the laboratory necessitated a removal to other quarters. This move was utilized to rebuild the apparatus and to increase the potential used for accelerating the protons up to 600,000 volts. In April, 1932, the first successful experiments were made, when a target of lithium was bombarded by protons. A scintillation screen placed near the target showed a large number

of scintillations due to α-particles resulting from the break-up of the lithium nucleus.

The development of this work owed a great deal to Rutherford's steady support and enthusiasm. He took little interest in the technical side of the work or even in the actual achievement of producing a beam of high-speed protons. His only interest was in the application of the apparatus to the object for which it had been built, the transmutation of matter. He himself now began to work in this field. With Oliphant, he built an apparatus for accelerating ions up to about 250,000 volts, overcoming the defects of the low voltage by increasing the ion current. Rutherford's view was that, at this early stage, detailed information about disintegration processes could only be obtained from experiments on the light elements, and for these low voltages were quite suitable. He was specially interested in establishing the energy relations in the processes. The generosity of Professor G. N. Lewis in presenting some of the first heavy water he prepared, enabled Rutherford and Oliphant to use deuterons as bombarding particles, and with these they found many striking nuclear reactions. It is of interest to record that in some experiments in which deuterium was bombarded by deuterons they obtained evidence of the existence of a hydrogen isotope of mass 3 and of a helium isotope of mass 3, the latter thus being the particle that Rutherford once thought he had found in the disintegration of nitrogen and oxygen by α-particles.

The transmutation of elements, so long and so often sought and at last by him achieved, the crowning triumph of his life's work, held for Rutherford a profound fascination. Perhaps he dimly foresaw the boundless possibilities, not yet conceivable. He was able to convey some of this quiet satisfaction and enthusiasm in that last book of his, *The Newer Alchemy*,* which has given so much pleasure to many readers of varied types of thought.

This work on disintegration by high-speed ions was pushed on with great vigour, and he and Oliphant, with various collaborators, obtained a great many interesting and important results. The energy relations in some of the processes led Rutherford and Oliphant to the conclusion that the values accepted for the atomic masses of the light elements were inconsistent. They deduced, from their experiments, a new set of atomic masses and this work acted as a fresh stimulus to measurements by Aston using the mass spectrograph.

It became increasingly clear to Rutherford that a better technique in producing and using large voltages was needed and that a special laboratory

* Cambridge, 1937.

for this work was desirable. Just at this time it was proposed to move the Library of the Cambridge Philosophical Society, and the site was acquired for the suggested High Tension Laboratory. Designs were prepared, and, with the ready cooperation of the architect, Mr. Holden, the laboratory was soon begun and, though building was delayed by shortage of material, it was ready for occupation in April, 1937. Meanwhile, Cockcroft and Oliphant, after much consultation between the workers concerned in the disintegration experiments, had been designing and developing new methods of producing high D.C. voltages. In the end, however, it was decided to buy the apparatus from Philips of Eindhoven, and this plant was installed in the High Tension Laboratory soon after the building was completed. The usual difficulties in obtaining well-focussed and well-directed beams of ions of great velocity were soon overcome. At the time of his death the new laboratory was in full operation and Rutherford was looking forward to a period of great activity.

During the course of the work already described much new information had been gathered about the properties of the α-particle. G. H. Henderson had made accurate measurements of the ionization curve and in 1922 discovered the surprising phenomenon of the capture and loss of electrons as the α-particle passed through matter. Rutherford was very interested in this effect and himself worked for some time on it. Briggs made very careful measurements of the initial velocities of the α-particles from some radioactive elements and investigated the retardation and straggling of the beam of particles in passing through matter. Blackett used the expansion chamber to study the collisions of α-particles with various light atoms, and, as mentioned already, succeeded in obtaining photographs showing the disintegration of the nitrogen nucleus. Kapitza measured the heating effect of a beam of α-particles at various points of their range. He deduced from his results a velocity-range relation for the α-particle which conflicted with that found by Blackett, and this discrepancy led him, in order to support his results by a more direct method, to develop a means of obtaining very strong magnetic fields. But the researches, even only those immediately bearing on the α-particle and its properties, are too numerous to mention here. We must, however, refer to the development of electrical methods of counting particles. It had become evident that, if further advances in such researches as those on artificial disintegration and scattering were to be made, the scintillation method must be replaced by one less tedious and more generally applicable. Some attempts had been made in the early days to amplify the ionization current produced by a single α-particle by means of valves, but they were not successful. Later, when valves had improved,

Greinacher (in Zürich) showed how it could be done, and his method was adapted and improved in the Cavendish by Ward and Wynn-Williams. The linear valve amplifier, as it was called, was then rapidly put into use in many experiments in the laboratory. Rutherford himself, first with Ward and Wynn-Williams and later with other collaborators, applied the electrical counting method to the accurate measurement of α-particle ranges and to a detailed investigation of the fine structure of the α-particle emission from various bodies. The electrical method was also largely responsible for the rapid progress in the disintegration experiments, for (although the scintillation method was used by Cockcroft and Walton in the first experiments) the zinc sulphide screen was soon displaced by the electric counter, to the benefit of all concerned.

The investigations made in the Cavendish during this period were varied as well as numerous. Ellis, carrying on the experiments of Rutherford, Robinson, and Rawlinson (interrupted by the war), found the connexion between the β-ray lines and the γ-radiation. He showed how this phenomenon could be used to investigate the γ-ray spectra of the radioactive elements and how it indicated that atomic nuclei have discrete energy levels. With his collaborators, he made a very detailed study of β-ray and γ-ray spectra. He also showed definitely that the disintegration electrons were emitted with energies distributed over a wide range and he focussed attention on the very perplexing problem of the β-ray emission. Blackett, after much work on the α-rays, turned his attention to the cosmic radiation and found, with Occhialini, the beautiful phenomenon of " showers " and confirmed Anderson's discovery of the presence of the positive electron. Much other work was also prosecuted in the laboratory—by Oliphant on the emission of positive ions and their interaction with surfaces, by Massey and Bullard and others on the scattering of slow electrons by atoms.

So far as it was possible to do so within the accommodation and resources of the laboratory, Rutherford sought to encourage other important lines of work. Among these was the school of wireless research developed by Appleton and continued by Ratcliffe ; and the work of Kapitza which led to the building of the Royal Society Mond Laboratory for low temperature investigations. It has already been told that the discrepancy between his results on the range-velocity relation for α-particles and those of Blackett led Kapitza to search for a method of producing high magnetic fields to bend the α-particles in their paths through an expansion chamber. He first built a large accumulator battery, which on short circuit produced magnetic fields up to 100,000 gauss. Impressed by this success, the Department of Scientific and

Industrial Research agreed to finance the construction of a large generator, which delivered 40,000 KW for a short period, during which fields of over 300,000 gauss were produced and used in experiments on the effects of magnetic fields on the electrical resistance of metals. This work led naturally to a demand for lower temperatures and in 1929 the Department of Scientific and Industrial Research made possible the construction of a liquid hydrogen plant. The scheme was finally rounded off in 1931 by the offer of the Royal Society to devote some of the funds of the Mond Bequest to the construction of a laboratory for magnetic and low temperature work. To this Royal Society Mond Laboratory the earlier apparatus was moved, and Kapitza began to build a plant for the production of liquid helium. It is typical of Kapitza that he was not content to adopt an existing design of liquefier, but approached the problem anew and finally developed a liquefier which eliminated completely the necessity for using liquid hydrogen in the liquefaction process. The subsequent history of this work needs no description here. The loss of Kapitza was a great disappointment to Rutherford and he was greatly concerned for the future of Kapitza's work ; his capable and diplomatic handling of the situation showed at their best his vision and shrewd judgement.

During his years in Cambridge, Rutherford's influence spread far and wide. As his insight and sound judgement became more widely appreciated, the claims on his time and services grew. He was consulted on awards and appointments by societies, universities, and government departments. There were his annual lectures at the Royal Institution, of which he was Professor of Physics, where he demonstrated admirably his latest discoveries. He was in demand for lectures, meetings, and addresses both at home and abroad.

In all these activities he took a great interest and he carried them out with conspicuous success. Only a man of extraordinary vigour and vitality could have continued, as Rutherford did, to carry out experimental work in the midst of his multifarious duties, and work of such importance as to keep him the outstanding leader. It was inevitable, as he had foreseen when accepting the Cavendish Chair, that his own direct contributions to physics should suffer in some degree, for though his enthusiasm and his simplicity of conception remained unimpaired to the end he was unable to give to research in his later years that continuous devotion and singleness of purpose so characteristic of him. He did not allow his external duties ever to interfere with his direction of the laboratory or with the supervision of the work, and he received his reward in the successes of his students and in the position which the Cavendish

Laboratory maintained in the scientific world. Many a stream of research work that bears the name of another may be traced back to a Rutherford source. Disciples came in large numbers to work under his direction. Most of these were young men with little or no experience in research. Rutherford recognized clearly that the training of large numbers of students would hamper the progress of his own work, but he accepted it as his duty, and he came to regard the training of students in methods of research as of almost equal importance to the immediate advancement of knowledge. It would be difficult to over-estimate his influence in this direction, for there can be few universities in the British Empire which do not contain at least one of his students.

The number of men both in the formal classes and on the research side increased to such an extent that the laboratory became seriously overcrowded. Expansion took place into space made available by the removal of the Engineering Laboratory and, later, of the Zoological Laboratory. Such accommodation could only be temporary, and in 1935 an appeal was made for funds to provide a suitable extension of the Cavendish Laboratory. The generous gift of £250,000 from Lord Austin relieved Rutherford's anxieties and at the time of his death he was considering schemes for the reconstruction of the old laboratory and the provision of new buildings. He leaves a goodly heritage and a difficult task to his successor.

We are grateful to J. D. Cockcroft and M. L. E. Oliphant for their help in this section on life at Cambridge.

Science and Industry

The teeming population of these islands has to be fed. To provide food, all of which cannot be grown at home, it is necessary to export in large quantities goods of quality. This can only be done by maintaining high standards in all branches of physics, chemistry, and engineering. Rutherford was deeply interested in all such questions and for seven years acted with enthusiasm as Chairman of the Advisory Council of Scientific and Industrial Research. No one knows of his services better than Sir Frank Smith, F.R.S., who wrote : " It was an article of faith with him that the future of Great Britain depends upon the effective use of Science by Industry ". And again : " One of the most original minds in the history of physics found an equal interest in pressing the claims of science to be allowed to serve industry, no less in the day-to-day routine of manufacturing process than in those major advances of knowledge which, in effect, develop new industries out of old ones. The

debt which the nation owes to Lord Rutherford for his work as Chairman of our Council should take its due place in our grateful memories of the man ".

He gave the twelfth annual Norman Lockyer lecture (1936) on " Science and Development " in the Hall of the Goldsmiths' Company, and he then referred to the difficulties in the laboratory work of his young days in New Zealand and said that he had " seen the great change in laboratory technique and the development of new instruments and methods of measurement ".

Moreover, advances in physics and in all branches of engineering act and react on one another to their mutual progress and betterment.

Honours

In 1893 Rutherford obtained his M.A. degree with honours in Mathematics and Physics from the University of New Zealand, and in 1894 he was elected to an 1851 Exhibition Scholarship. He became Fellow of the Royal Society in 1902, and three years later was awarded the Rumford Medal. He was Nobel Laureate for *Chemistry*, 1908, and received the honour of knighthood in 1914. He was elected Fellow of Trinity College, Cambridge (1919), and awarded the Copley Medal of the Royal Society (1922). He was President of the British Association for the Advancement of Science (1922). He received the great distinction of the Order of Merit (1925). He was President of the Royal Society (1925–1930), and he was Professor of Natural Philosophy at the Royal Institution. He was President of the Institute of Physics and an 1851 Exhibition Commissioner. He received the Barnard Medal from Columbia University, the Franklin Medal (1924) from the Franklin Institute, Philadelphia ; the Albert Medal (1928) from the Royal Society of Arts ; the Faraday Medal (1930) from the Institute of Electrical Engineers ; and, as early as 1908, the Bressa Prize (£384) from the Academy of Sciences at Turin—his first substantial recognition. He received honorary degrees from about twenty universities scattered over the world, and he was an honorary member of numerous Societies and Academies, as recorded in the Year Book of the Royal Society.

In 1931 he was created Baron Rutherford of Nelson and took his seat in the House of Lords.

In 1937 he was Elected President of the twenty-fifth (silver jubilee) Meeting of the Indian Science Congress joined by nearly a hundred representatives of the British Association for the Advancement of Science. His presidential address, prepared about two months before his untimely death, was read (January, 1938) by his successor, Sir James Jeans, who

paid a noble tribute to this friend he so admired and respected. He said :—

" In truth most of his investigations were key investigations, each brilliant in its simplicity of conception and far-reaching in its consequences . . . In his flair for the right line of approach to a problem, as well as in the simple directness of his methods of attack, he often reminds us of Faraday, but he had two great advantages which Faraday did not possess—first, exuberant bodily health and energy, and second, the opportunity and capacity to direct a band of enthusiastic co-workers. Great though Faraday's output of work was, it seems to me that to match Rutherford's work in quantity as well as in quality, we must go back to Newton.

" Voltaire once said that Newton was more fortunate than any other scientist could ever be, since it could fall to only one man to discover the laws which govern the universe. Had he lived in a later age, he might have said something similar of Rutherford and the realm of the infinitely small ; for Rutherford was the Newton of atomic physics. In some respects he was more fortunate than Newton ; there was nothing in Rutherford's life to compare with the years which Newton spent in a vain search for the philosopher's stone, or with Newton's output of misleading optical theories, or with his bitter quarrels with his contemporaries. Rutherford was ever the happy warrior—happy in his work, happy in its outcome, and happy in its human contacts ".

Home Life

As an undergraduate Rutherford had known Mary G. Newton, a fellow student at Christchurch College, N.Z., and their engagement was announced in 1897. Her father was English and her mother Irish. In 1900 Rutherford returned from Montreal to New Zealand and married Mary Newton, and then they returned to a house in St. Famille Street, Montreal. From that time Lady Rutherford shielded him from many of the time-consuming and troublesome contacts of life, typed his books, preserved and filed his papers, collected and arranged his reprints, selected and cared for his two homes and gardens of Newnham Cottage, Cambridge, and of that charming Chantry Cottage, quaintly enough part of New Zealand farm, in Wiltshire.

Their one child, Eileen, married R. H. Fowler, now Plummer Professor of Mathematical Physics at Cambridge, and there can rarely have been a son-in-law so completely genial in outlook and ability. The sudden death of his daughter in 1930 was the chief sorrow of Rutherford's life. The four promising grandchildren, two sons and two daughters, have

been to him a great delight. His many personal letters show clearly the pleasure he found in his private life, particularly in the fresh open air of Chute and the surroundings of Chantry Cottage. He and his wife entertained visitors, colleagues, and students in a genial way that made all feel quickly at home.

Outdoor life always charmed Rutherford, whether playing golf, bathing, motoring, or tree-felling. Not long ago, somewhat tired after clearing some bush, he turned homewards quoting Spenser—

" Sleep after toil, port after stormy seas,
Ease after war, death after life, does greatly please ".

Rutherford Himself

To describe the scientific life and achievements of this Newton of the Atom is a tremendous undertaking, and, if completed, there would still remain the Man Himself ! Anything that is written or said seems too little and yet too much, because of the blend of simplicity with greatness.

A man who knew him well for thirty years remarked, " Rutherford never made an enemy and never lost a friend ". That seems to be a true statement, and it is the more remarkable because he was an outspoken man ; but what he said came from his whole kindly nature, and not from his intellect alone.

He was a great lover of peace—but not at any price ! He had a quick sympathy with the oppressed, and he was a friend to the outcast. During four years he was Chairman of the Society for the Protection of Science and Learning, called into being by a new and most unfortunate order of events.

" Like Faraday, Rutherford lived to be a centre of universal affection as well as esteem ".

" He had, of course, a volcanic energy and an intense enthusiasm—his most obvious characteristic—and an immense capacity for work. A ' clever ' man with these advantages can produce notable work, but he would not be a Rutherford. Rutherford had no cleverness—just greatness ".

He could not fail to be aware of this, but, like his honours, it left him quite unspoiled. On the occasion of one of his discoveries, the writer said to him : " You are a lucky man, Rutherford, always on the crest of the wave ! " To which he laughingly replied, " Well ! I made the wave, didn't I ? " and added soberly, " At least to some extent ". Truly his wave went with him wherever he went, a fine wave, lit by the sunbeams, for he had the three precious gifts of the poet—deep insight,

powerful imagination, and a profound love of truth. And so it came to pass that he was " always a charming blend of boy, man, and genius ".

There came a short, sharp illness, an operation, and in spite of every care he died on 19 October, 1937.

Six days later his remains were laid to rest in the Abbey near the graves of Newton, Kelvin, Darwin, and Sir John Herschel. He had been created Baron Rutherford of Nelson in 1931, but he will always be Rutherford. The words of the Sub-Dean of Westminster remain with us :

" We thank thee for the life and works of Ernest our brother ".

A. S. Eve.
J. Chadwick.

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